Tevatron Searches for Higgs Bosons beyond the Standard Model

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Higgs Bosons in the MSSM

In contrast to the SM, the MSSM Higgs sector is the most predictive part of the model!

- Starting from two Higgs doublets H_{u}, H_{d}, five physical Higgs bosons remain upon EWSB: $H^{\pm}$, h, H, A
- Tree level Higgs boson masses, couplings can all be expressed as a function of m_A and $\tan\beta \equiv v_u/v_d$. Relative to SM couplings:

SM particle type	h coupling	H coupling	A coupling
up-type quarks	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\cot\beta$
down-type quarks, $\ell^{\pm}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\tan\beta$
W and Z bosons	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$	0

- $H^{\pm}tb$ coupling $\sim V_{tb}m_t\cot\beta(1-\gamma_5)+m_b\tan\beta(1+\gamma_5)$

Radiative corrections accounted for in scenarios.

- Typical: no-mixing (between $\tilde{t}_{\mathrm{L}}$, $\tilde{t}_{\mathrm{R}}$), m_h^{max} (tuned to obtain highest possible m_h)
- Accounting for radiative corrections, $m_h \lesssim 135$ GeV

Tevatron Strategy

In the past, LEP analyses focused on *ZH* associated production:

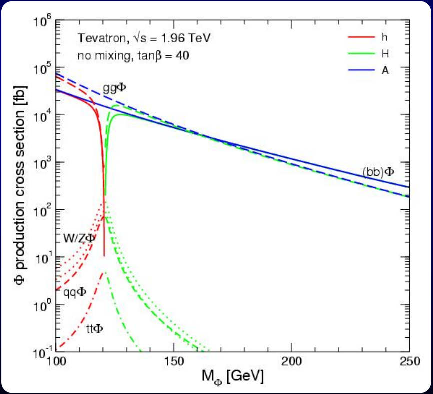
- for low $\tan\beta$, $\sin^2(\beta-\alpha) \approx 1 \Rightarrow m_h$ coverage as for SM
- low values of $\tan\beta$ "typically" excluded

Higgs boson production at the Tevatron can be enhanced significantly for high $\tan\beta$:

- m_h, m_A nearly degenerate for low m_A (and similar degeneracy m_H, m_A for high m_A)
- respective production cross sections almost identical
  - "other" CP even boson unobserved

Analyses don't attempt to identify individual Higgs bosons but look for overall excess

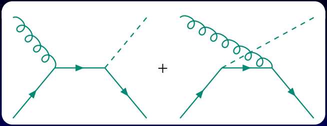
Tev4LHC Higgs WG



$\phi = A/h/H$

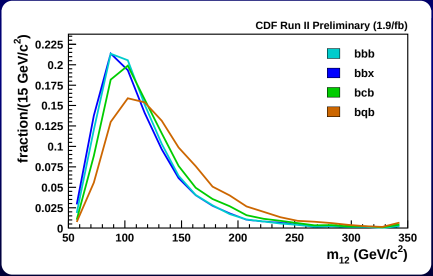
$h/H/A \to b\bar{b}$

- Largest branching fraction, $B \approx 0.9$
- Large QCD heavy flavour background
  $\Rightarrow$ require 3 b-tagged jets
- Even then, requires detailed understanding of background



New CDF analysis, 1.9 fb^{-1}:

- start from double-tagged data
- obtain templates for invariant mass (M_{12}) distribution of two leading b jets, b-tagging related variable (not shown)
- fit templates to triple-tagged data



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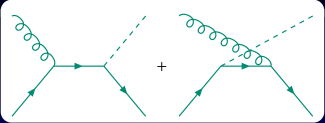

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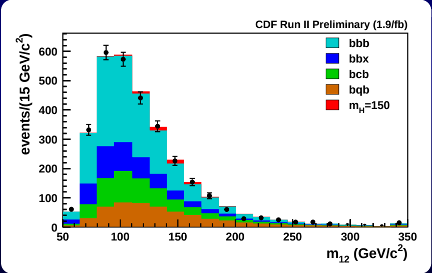
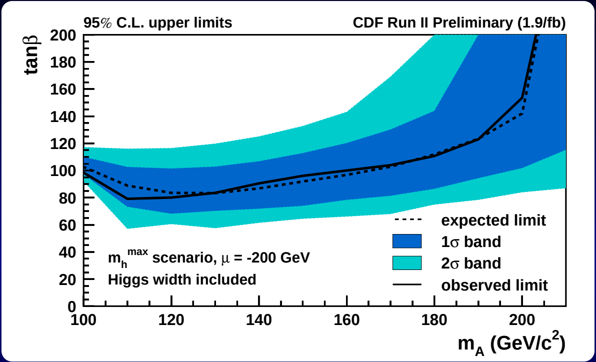


$h/H/A \to b\bar{b}$ (continued)

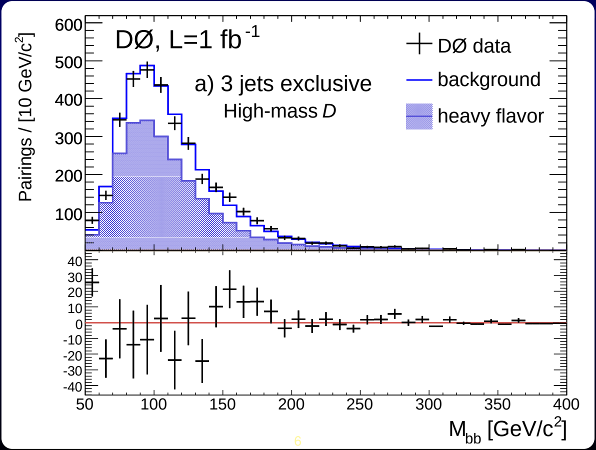


- Analysis improvements compared to previous analyses:
  - account for Higgs boson decay width (broadened shape more difficult to distinguish from background: worsened limits!)
  - more theory input on *b*-production mechanisms

$h/H/A \to b\bar{b}$ (continued)

Similar analysis (1 fb^{-1}) by DØ submitted for publication last week

- more theory input (use MC) to scale from double tagged to triple tagged samples
- use of multiple b-tagging criteria to improve knowledge of sample composition



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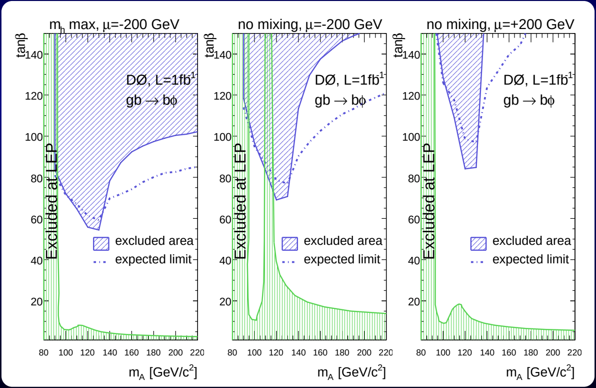
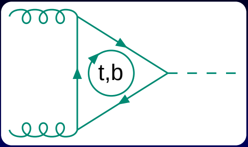
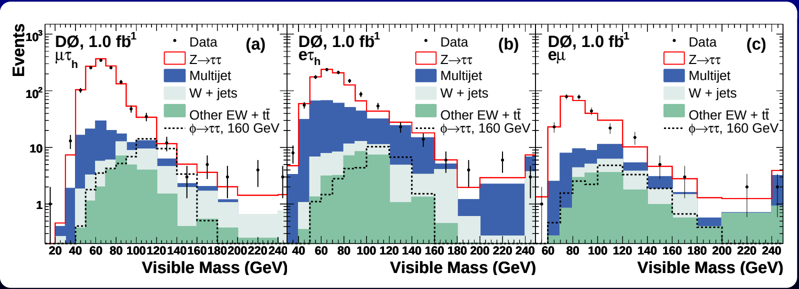


$h/H/A \to \tau^+\tau^-$

- The branching fraction for this decay ($B \approx 0.1$) is moderate. . .
- But its cleanliness (absence of QCD background) makes it a performant channel!
- Resolution in visible invariant mass $m_{\text{vis}} \equiv \sqrt{(p_{\tau 1} + p_{\tau 2} + \not{p}_T)^2}$ adequate

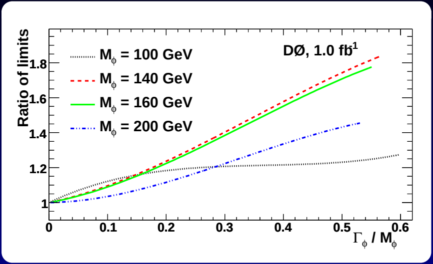


DØ just submitted a publication on 1 fb^{-1} using $\tau_e\tau_{\text{had}}$, $\tau_\mu\tau_{\text{had}}$, $\tau_e\tau_\mu$



$h/H/A \rightarrow \tau^+\tau^-$ (continued)

- increased Higgs decay width accounted for by correcting cross section limits: $\Gamma/m < 0.1 \Rightarrow$ small effect



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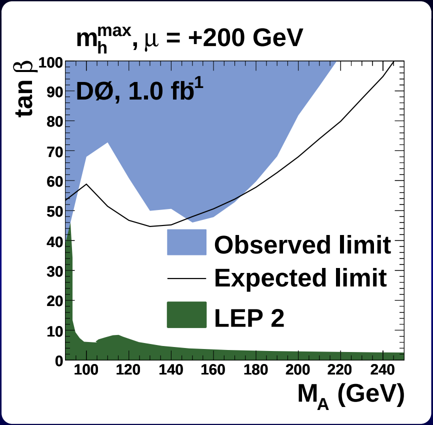

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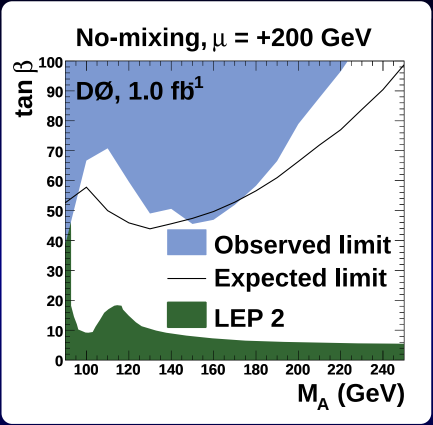

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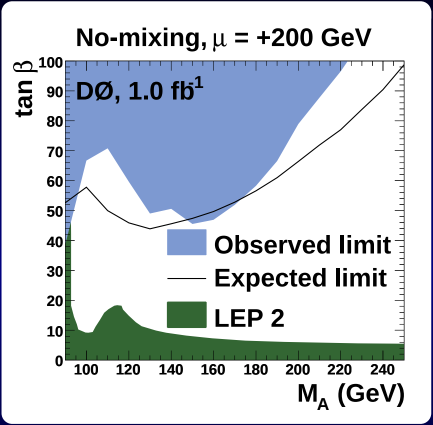

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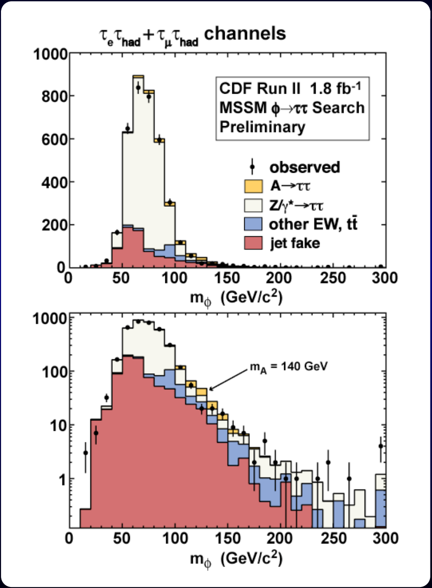

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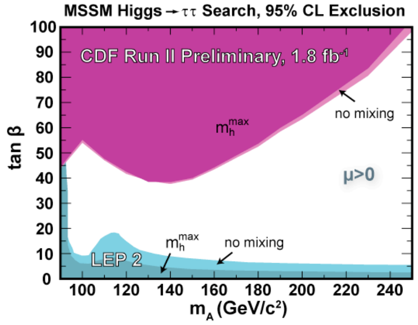
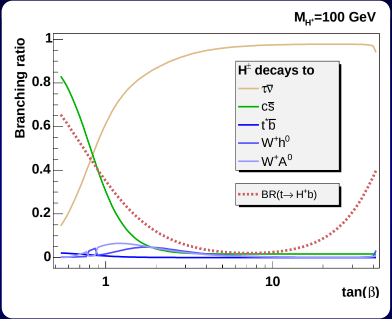


- Limits generally more restrictive than for decays to $b\bar{b}$ final states
- Starting to probe $\tan\beta$ region interesting from other points of view
  - Yukawa coupling unification in SO(10)
  - dark matter co-annihilation region

Charged Higgs Bosons

Charged Higgs bosons $H^{\pm}$ have been searched for, for the case $m_{H^{\pm}} < m_t - m_b$: production of $H^{\pm}$ in top quark decays



tan β dependence of $H^{\pm}$ decay as well as production

Already exploited in '06 CDF analysis looking for $H^{+} \to \tau^{+}\nu_{\tau}$ decays (high tan β)

Recent DØ analysis, 1 fb^{-1}:

Exploits existing $\sigma(t\bar{t})$ measurements to search for $H^{+} \to c\bar{s}$ with $m_{H^{\pm}} \approx m_W$: sensitivity of

$$R \equiv \frac{\sigma(t\bar{t})_{\ell+\text{jets}}}{\sigma(t\bar{t})_{\ell\ell}} = 1.21^{+0.27}_{-0.26}$$

to extra contributions in the ℓ+jets channel $\Rightarrow B(t \to H^{+}b) < 0.35$

NB: Relevant for low-tan β MSSM, but $B(H^{+} \to c\bar{s}) \approx 1$ also possible in multi-Higgs-doublet models

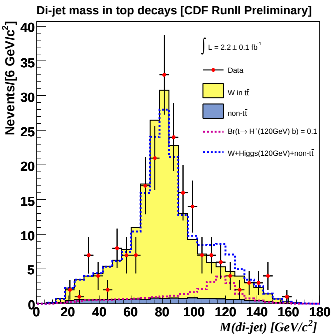
Charged Higgs Bosons (continued)

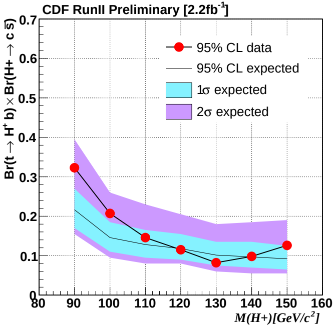
But one can do more! For $m_{H^\pm} > m_W$, $t \to H^+ b$ and $t \to W^+ b$ will look different.

New CDF analysis, 2.2 fb^{-1} of ℓ+jets data:

- 4-jet, double b-tagged events
- non-b jets should combine to form $W^\pm$ or $H^\pm$

template fit with $m_{H^\pm} = 120$ GeV



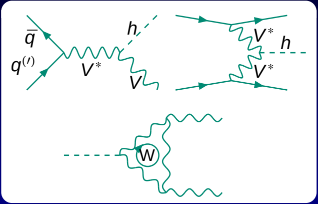


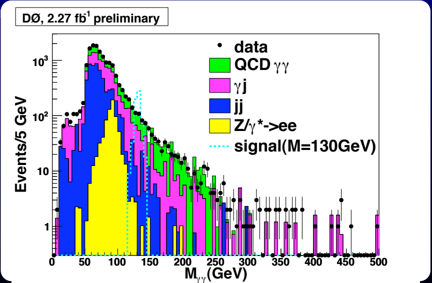
Fermiophobic Higgs Bosons

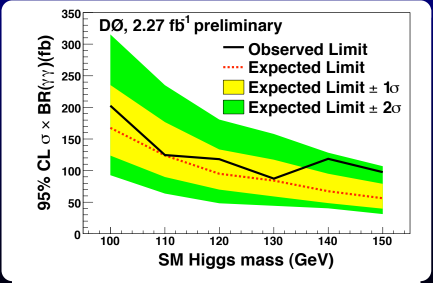
Scenarios are possible where the Higgs boson couplings to fermions are small (*e.g.* MSSM "small $\alpha_{\rm eff}$" scenario)

DØ have looked at "fermiophobic" Higgs models (couplings to all fermions suppressed) in 2.3 fb^{-1} dataset

- for $m_h \lesssim 100$ GeV: $h \to \gamma\gamma$ main decay mode
- exploits calorimeter capabilities to reduce QCD background







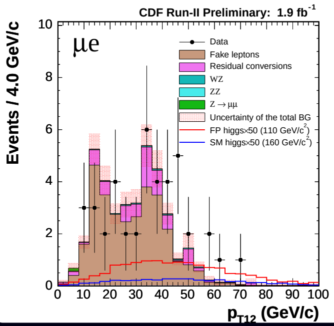
Fermiophobic Higgs Bosons (continued)

For higher m_h, the decay mode $h \to W^+W^-$ becomes important.

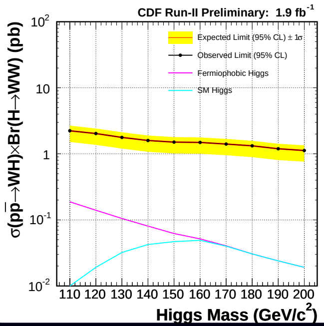
CDF analysis (1.9 fb^{-1}) looking for $W^\pm h \to W^\pm W^\pm W^\mp$:

- spinoff of corresponding SM channel: different $B(h \to W^+W^-)$
- very clean: like-sign dilepton signal (e/μ)

(before final cuts on p_{T2}, dilepton p_T)



limits similar to '07 DØ analysis

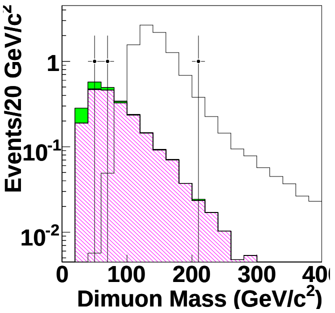


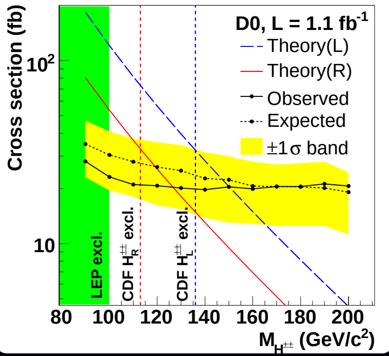
Doubly Charged Higgs Bosons

$H^{\pm\pm}$ can be found *e.g.* in the Higgs triplet fields of a number of models (*e.g.* LR-symmetric, little Higgs). At the Tevatron they could be produced via $q\bar{q} \rightarrow \gamma/Z \rightarrow H^{++}H^{--}$

DØ publication (1.1 fb^{-1}) looking for $H^{++}H^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$:

- require two like-sign muons, plus a third muon
- again very clean: backgrounds from WZ, ZZ production





Technicolour

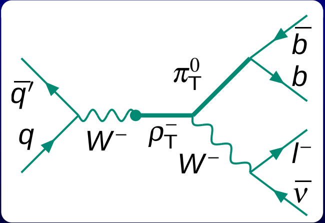
Not Higgs physics proper! EWSB without fundamental scalars

- extra SU(N_{TC}) interaction becoming strong at $E < \mathcal{O}$(1 TeV), forming techni-fermion pair condensates
  - in the scalar case, mixtures of Goldstone bosons π_{T} and W_{L}, Z_{L}
- yet another interaction required to provide fermion masses

Analyses being done in context of TechniColour Strawman Model: low-E phenomenology dealing with π_{T}, ρ_{T} (and π_{T8}, ρ_{T8}) only

New CDF analysis (1.9 fb^{-1}) looking for $\rho_{\mathrm{T}} \to \pi_{\mathrm{T}} W \to b\bar{b}\ell\nu$ ($\ell =$ e, μ):

- relevant for $m_W + m_{\pi_{\mathrm{T}}} < m_{\rho_{\mathrm{T}}} < 2m_{\pi_{\mathrm{T}}}$
- same final state as SM WH but production cross section $\mathcal{O}$(pb)



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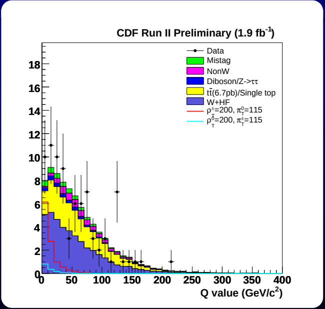
binned ML fit in m_{jj} and $Q \equiv m_{jjW} - m_{jj} - m_W$



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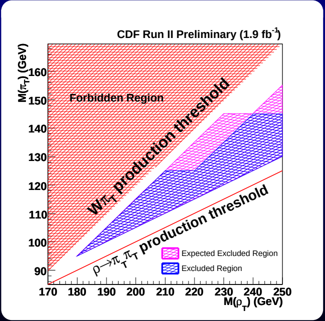
NB: extends exclusion region from '06 DØ analysis but different model parameters M_V, M_A, Q_U



Outlook

Good progress in non-SM Higgs boson searches

- many analyses cover $> 1\mathrm{fb}^{-1}$ datasets, and much more to come
- starting to probe “interesting” regions of parameter space
  - especially in the “standard” $m_h^{\max}$ and no-mixing scenarios

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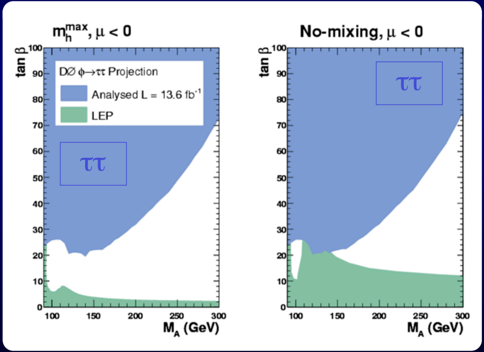
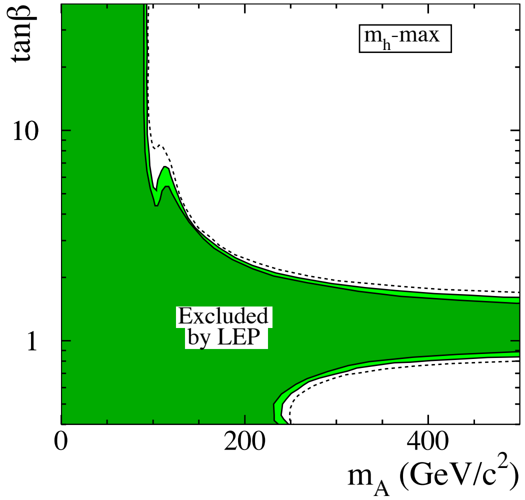


MSSM Benchmark Points

Scenario	m_h^{max}	no-mixing
Mixing parameter X_t	2 TeV	0 TeV
Higgs mass parameter μ	$\pm$200 GeV	$\pm$200 GeV
Gaugino mass term M_2	200 GeV	200 GeV
Gluino mass $m_{\tilde{g}}$	0.8 TeV	1.6 TeV
Common scalar mass M_{SUSY}	1 TeV	2 TeV

LEP Exclusion Limits



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